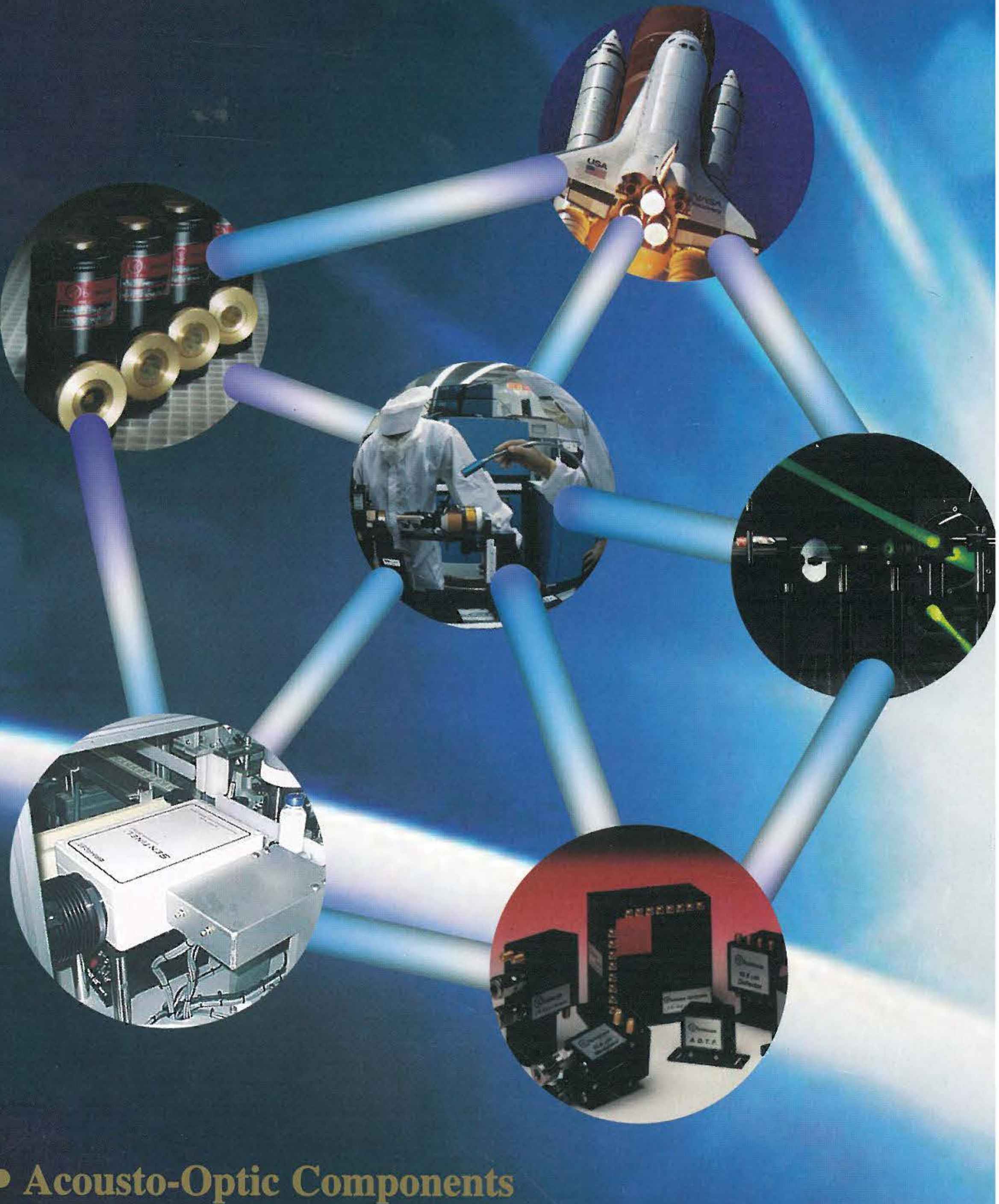
BRIMROSE



- **Acousto-Optic Components**
- **Acousto-Optic Tunable Filters**
- **Diode Pumped Solid State Lasers**
- **IR Photovoltaic Detectors**
- **AOTF-NIR Process Control Spectrometers**

brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Acousto-Optic Tunable Filters

July 1999

All specifications in this catalog are subject to change without notice.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Directory

brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

AOTF SPECTROSCOPY

A POWERFUL NEW TOOL IN NEAR INFRARED SPECTROSCOPY

In this application note we discuss how the special properties of an acousto-optic tunable filter (AOTF) can be used to eliminate many of the practical problems associated with industrial or process control near-infrared spectroscopy.

INTRODUCTION

Near-infrared spectroscopy is a technique that has gained wide-spread acceptance in recent years as a powerful diagnostic tool, particularly for quality assurance and process control purposes. It has already been proven in such diverse applications as quantitative analysis of pharmaceuticals, cosmetics and gasoline (including octane number), manufacturing and quality assurance for soft drinks and beer, confirming the ripeness of fruit, and spectroscopic imaging of biological and medical materials.

To successfully deploy NIR spectroscopy in most real applications requires recording data at a number of different wavelengths. Some type of monochromator, or wavelength selection device, is therefore an essential part of any NIR spectrometer. Unfortunately, traditional monochromators (using diffraction gratings) require careful handling and frequent calibration. In addition, their performance is easily degraded in an industrial environment, making them less than perfect for use in an on-line process control application. It also takes a relatively long time to scan such a device between different wavelengths reproducibly.

The acousto-optic tunable filter (AOTF) on the other hand has almost ideal properties for performing NIR spectroscopy. It is an all solid-state tunable filter with no moving parts and is therefore immune to orientation changes or even severe mechanical shock and vibrations. This comparatively new technology is capable of excellent resolution and can be easily incorporated in a sealed system using fiber optics for measuring remote samples or for use in extremely hostile conditions. Not only does it have no moving parts to calibrate, but the AOTF is also a high speed programmable device capable of randomly accessing thousands of precise wavelengths in less than a second, making it an excellent tool for NIR spectroscopy. Consequently, AOTF based spectrometers can increase the power of NIR spectroscopy to such a degree that they are expected to literally revolutionize the field, opening up a host of new applications, including spectroscopic imaging*, as well as improving the capabilities of existing ones.

* See for example, P.J. Treado, I.W. Levin and E.N. Lewis, Applied Spectroscopy, 46, 4 1992

NEAR INFRARED SPECTROSCOPY

The near-infrared, or NIR, spectral region is loosely defined as the wavelength region from 700 nm out to 2-3 microns. Many molecules have characteristic vibrational overtones ($\Delta\upsilon>1$) that give rise to absorption bands in this part of the electromagnetic spectrum. Consequently, NIR absorption spectra can be used to identify molecular species and evaluate concentrations or mole fractions in complex mixtures as diverse as soft drinks and formulated cosmetics.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Vibrational Band Overlap

The strongest NIR absorption bands are usually associated with the first and second overtones (or combination bands) of high frequency stretching vibrations. The wavelengths at which these vibrations occur for a particular chemical is a function of its structure and composition: the first overtone of O-H stretching vibrations are usually in the 1350 - 1450nm region, whereas the second overtone of a C-H stretching vibration can vary from approximately 1070 nm in a vinyl group to 2500 nm in some aliphatic molecules.

Unfortunately, interpreting near-infrared (NIR) spectra to derive the composition or concentrations of constituents is fairly complex in comparison to many other spectroscopic techniques. Concentrations or other important parameters cannot be measured solely by the absorption or reflectivity value at a single NIR wavelength. The reasons for this difficulty are severe band congestion and overlap (see Figure 1). Since NIR absorption bands are broad, and because there may be several vibrational bands in the same spectral region (even for a single molecular species), significant problems are usually encountered during analysis.

For example, a sugar molecule may have several, slightly displaced but overlapping C-H stretches not to mention a host of weaker combination bands, making it difficult or impossible to resolve and identify individual vibrational bands. This problem may be additionally compounded by unpredictable light scattering and refractive index changes in the samples, producing sloping or variable baselines. Obviously this situation is further complicated in analyzing the NIR spectra of mixtures of two or more compounds. Such spectra rarely have any zero absorption or baseline regions making even simple evaluations of absolute intensities difficult (see Figure 1). For example, the absorption at a given wavelength may contain contributions from several vibrations within more than one molecular species or substance. Single point analysis of such spectra is therefore not optimal for quantitative analysis.

Spectral Analysis

The key to interpreting NIR spectra is on-line data processing and chemometrics, which has become possible with the advent of spectroscopic systems with intelligence in the form of dedicated, or in some cases, built-in microprocessors or PC's.

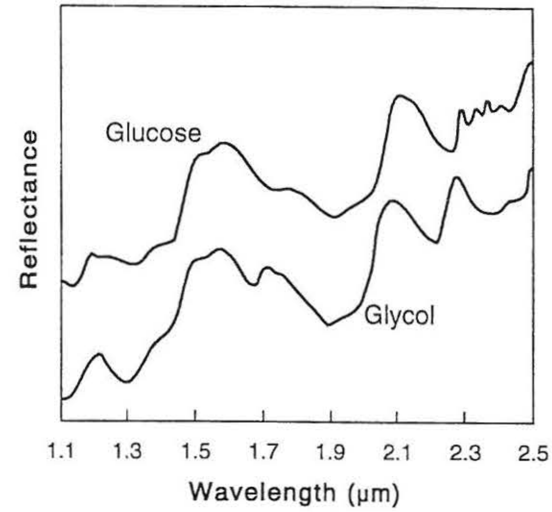


Figure 1. *The NIR spectra of two common organic materials, glucose and glycole.*

Typically, the analysis would proceed in up to four distinct phases: data collection, data processing, and finally calibration and prediction (chemometrics). The data collection phase entails choosing the appropriate experimental/ instrumental conditions under which to collect the data. This may involve determining the optimal wavelength range, the amount of signal - averaging to perform, or perhaps the choice between transmittance, reflectance, or transreflectance modes. The data processing or preprocessing phase refers to treating the data with a variety of digital techniques which have the affect of redistributing the information content of the spectrum to a form more tractable to the subsequent chemometric analysis. These include signal averaging, spectral subtraction or normalization, instrument response correction or the calculation of derivatives, and even more elaborate methods such as, spectral deconvolutions or maximum entropy calculations in some cases. Chemometrics refers to a variety of mathematical methods, including multivariate statistics, for analyzing or improving the analysis of chemical data. These methods allow, for example, the empirical interpretation of NIR spectra to yield highly accurate and reliable data on composition, mole fraction and even such complex parameters as the octane number of

gasoline. There are a wide variety of multivariate statistical approaches useful in NIR spectral analysis: Classical least squares (CLS), inverse least squares (ILS), partial least squares (PLS), and principal components regression (PCR).

The basic principles are the same for each method. The spectrometer's CPU records and stores spectra from a range of calibrated test samples. The software then tries to fit expressions that correlate spectral intensities to the known concentrations or other parameters of interest - within acceptable error limits determined by the quality of the data. These expressions may involve a few specific wavelengths from a spectrum or indeed the whole spectrum, depending on the analytical method employed. Once the instrument has derived these expressions it is able to simultaneously analyze and perform concentration predictions on unknown samples containing one or more components. As an example, Figure 2 shows the correlation between actual motor octane number and that predicted by NIR spectroscopy and multivariate spectral analysis for various blends of gasoline.

Limitations of Existing Technology

Whatever type of monochromator or wavelength filtering device is employed in a NIR spectrometer, it is desirable that it be programmable, with fast and accurate random access. For industrial applications the spectrometer must also be rugged without the need for frequent maintenance or recalibration. Several different technologies have been employed in NIR spectrometers but each has serious limitations, particularly in an on-line industrial situation. The scanning diffraction grating spectrometer is a well proven tool in many types of spectroscopy. However, it needs to be frequently recalibrated, is susceptible to mishandling and damage in hostile environments, and takes a finite time to scan between wavelengths. The newer grating spectrometers using a fixed grating and detector array are much faster and better suited to the industrial environment, needing less maintenance and/or recalibration. However, the selected wavelength is still a function of a precise geometrical arrangement between the grating and detector. Vibration or mishandling can thus cause "blurring" of the image on the array, which translates into reduced performance. Another limitation of this

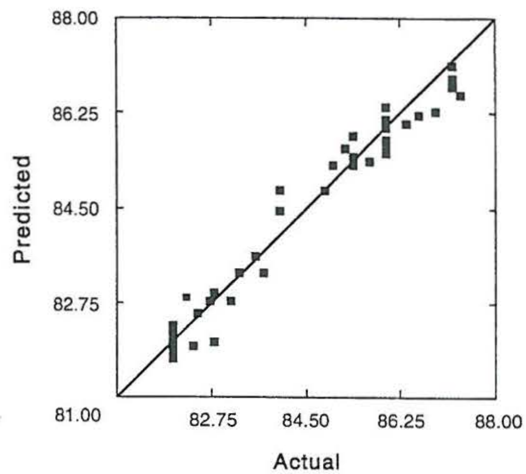


Figure 2. *Correlation of actual and NIR predicted motor octane number for various gasolines. Predictions based on multivariate correlation analysis. From J.J. Kelly et al., Anal. Chem. 1989, 61, 31.*

type of instrument is that they can be used in only one of two modes, to record widespread spectral data at low resolution, or a limited spectral region at higher resolution. Bandpass Filters simply do not offer the flexibility for most real world applications. A separate filter is needed for each wavelength data point. Fourier Transform (FT) spectrometers are available for the NIR spectral region and are capable of excellent resolution and sensitivity. Unfortunately since their operation involves precision translation of mirrors, their performance is also very sensitive to environment - vibrations and dust. In addition, they are relatively slow since they can only collect and compute spectral data over the entire combined bandpass of the instrument. Clearly, none of these technologies offers the required combination of speed, ruggedness, flexibility, reliability, and hands-off operation required in the vast majority of industrial applications, hence the interest in alternative technologies such as the AOTF.

WHAT IS AN AOTF?

Brief Description

An AOTF acts as an electronically tunable spectral bandpass filter. It is a solid state electro-optical device with no moving parts. It consists of a crystal in which acoustic

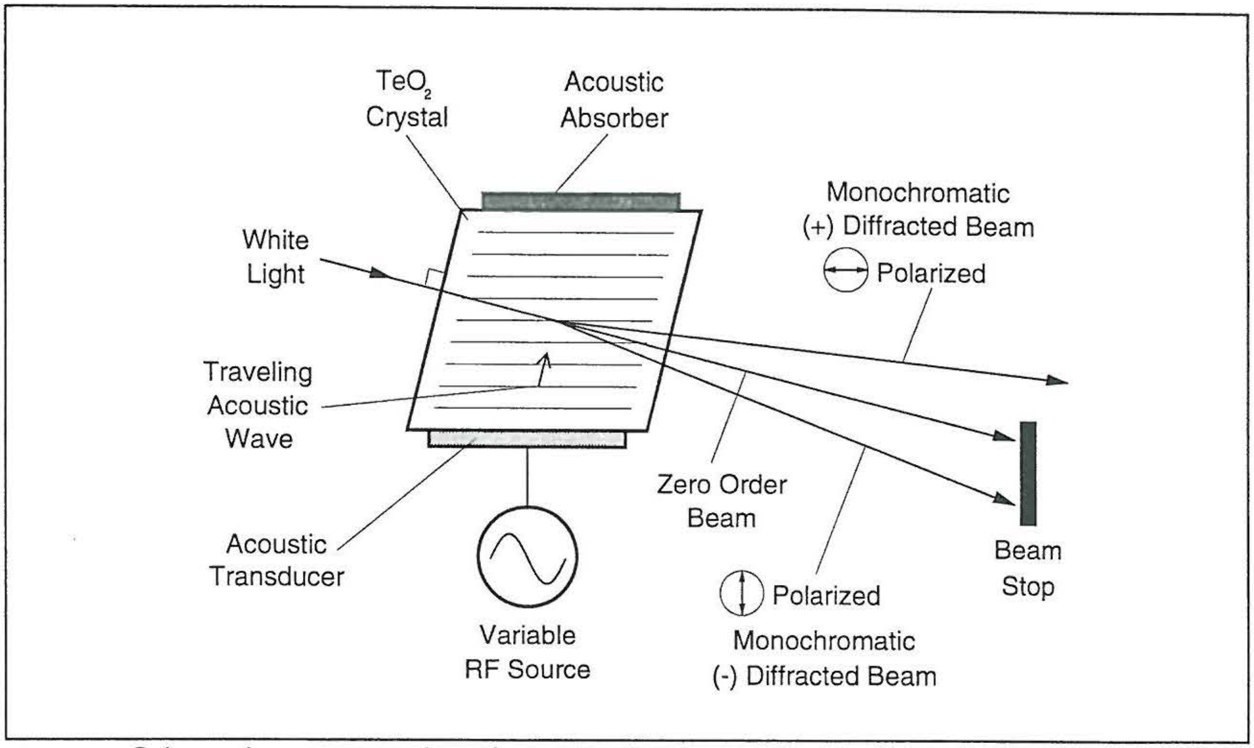


Figure 3. *Schematic representation of a non-collinear AOTF.*

(vibrational) waves, at radio frequencies (RF) are used to separate a single wavelength of light from a broadband or multi-color source. The wavelength of light selected is a function of the frequency of the RF applied to the crystal. Thus, by varying the frequency of the RF, the wavelength of the separated or filtered light can be varied. This wavelength is independent of device geometry.

Technical Details

The most common types of AOTF which operate in the NIR region use a crystal of Tellurium Dioxide (TeO_2) in a so-called non-collinear configuration - the acoustic and optical waves propagate at quite different angles through the crystal. Figure 3 is a schematic representation of a TeO_2 AOTF. A transducer is bonded to one side of the TeO_2 crystal. This transducer emits vibrations (acoustic waves) when RF is applied to it. The frequency of the vibrations equals the frequency of the applied RF. As these acoustic waves pass through the TeO_2, they cause the crystal lattice to be alternately compressed and relaxed. The resultant refractive index variations act like a transmission diffraction grating or Bragg diffracter. Unlike a classical diffraction grating, however, the AOTF only diffracts one specific wavelength of light, so that it acts more like a filter than a diffraction grating. This is a result of the fact that the diffraction takes place over an extended volume, not just at a surface or plane, and that the diffraction pattern is moving in real time. The wavelength of light that is diffracted is determined by the "phase matching" condition as described:

$$\lambda = \Delta n \, \alpha \, \upsilon_a / f_a$$

where Δn is the birefringence of the TeO_2 crystal, υ_a and f_a are the velocity and frequency of the acoustic wave, and α is a complex parameter depending on the design of the AOTF. The wavelength of the light that is selected by this diffraction can therefore be varied simply by changing the frequency of the applied RF. As indicated in the figure, the diffracted light intensity is directed into two first order beams, termed the (+) and (-) beams. These beams are orthogonally polarized, which is utilized in certain applications. To use the AOTF as a tunable filter, a beam stop is used to block the undiffracted, broadband light and the (+) and/or (-) monochromatic light is directed to the experiment. The angle between the beams is a function of device design, but is typically a few degrees. The bandwidth of the selected light depends on the device and the

wavelength of operation, and can be as narrow as 1nm FWHM. Transmission efficiencies are high (up to 98%), with the intensity divided between the (+) and (-) beams. Another useful and unique feature of the AOTF is its ability to precisely and rapidly adjust the intensity of the diffracted (filtered) light by varying the RF power.

BENEFITS OF AOTF'S IN NIR SPECTROSCOPY

Since the AOTF acts as a tunable filter, it can act as the monochromator at the heart of a NIR spectrometer. In the following notes we discuss how the various features of an AOTF benefit NIR spectroscopic applications. These benefits make the AOTF more than just another technology for consideration, but unquestionably the ideal tool for NIR spectroscopy.

Repeatability/Calibration

The AOTF is an all solid state device with no moving parts, and the transmitted wavelength is independent of device geometry. In fact, the transmitted wavelength is determined only by the frequency of the applied RF, which can be generated with digital precision. This means that once an AOTF or AOTF spectrometer is factory calibrated, it will not need to be recalibrated. Since NIR applications usually require measurements at multiple wavelengths, short and long term wavelength repeatability are highly advantageous. As an example, a typical TeO_2 AOTF has a guaranteed wavelength repeatability error of less than ±0.05 nm.

Wavelength Purity

In NIR spectroscopic measurements, out of band transmission must be kept to a minimum, preferably zero. Out of band transmission is defined as the light transmitted at wavelengths other than the theoretical narrow band defined by the filtering device, in this case the AOTF. Clearly, out of band transmissions could cause severe problems in NIR spectroscopy making it difficult if not impossible to derive meaningful answers from the corrupted experimental data. Fortunately, the AOTF excels in this area too, with out of band transmissions as low as 10^{-5} for some devices (see Figure 4).

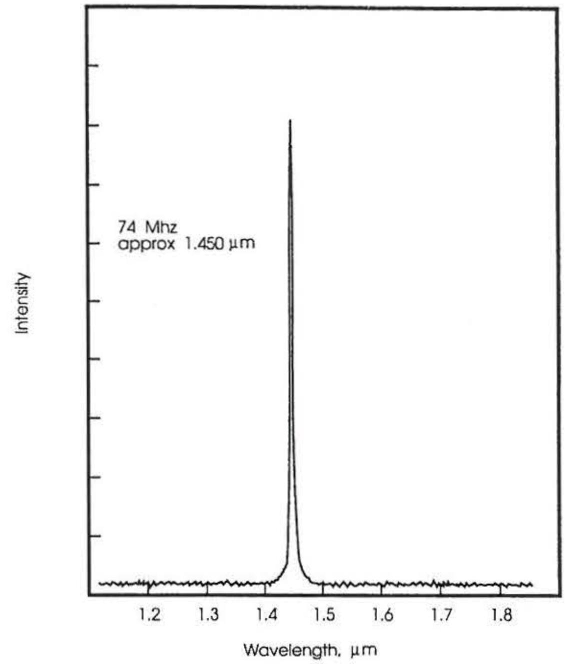


Figure 4. *Plot of output spectrum of a Brimrose model TEAF-.8-1.8S AOTF tuned to 1450nm. Note absence of out band transmissions.*

Speed/Random Access

When the frequency of the rf is changed, the rate limiting factor in changing the wavelength is the time it takes for the changed RF to fill the AOTF crystal - typically 20 microseconds. This means that entire spectra can be scanned at very high speed, or discrete wavelengths may be accessed at rates of 10 KHz or greater, even when separated by hundreds of nanometers.

Computer Control/Integration

One of the most useful features of the AOTF is its high degree of controllability or programmability. In commercial AOTF's, the RF generator is interfaced directly to a microprocessor or computer. This enables an AOTF based spectrometer to be programmed to scan or access different wavelengths very rapidly, and even to change the output intensity at those wavelengths. In use, therefore, it is easily integrated into almost any computer controlled test or experiment.

Closed Loop Process Control

Computer control and/or on-board intelligence makes an AOTF spectrometer an ideal tool for closed loop process control. For example, an instrument of this type could reliably and rapidly measure the aspartane concentration in soda and, as a result, control the blending process in real-time.

Rugged Device/No Moving Parts

AOTF's are both compact and rugged. Clearly a device with no moving parts is much more insensitive to damage in industrial applications. Just as important, short of actually breaking the device, vibrations and shocks will not affect the wavelength calibration.

Closed System/Fiber Coupling

Other hazards presented by the industrial environment may include dust and corrosive vapors. The AOTF is easily incorporated into a bidirectional (bifurcated) fiber system as shown in Figure 5. In such a setup, the fiber is sealed directly to both the AOTF and detector to make a completely air-tight closed system. This allows remote sensing and also protects all the optical and electro-optical components from damage by dust or chemicals.

Efficiency/Sensitivity

The AOTF is a high efficiency device with transmission at the selected wavelength as high as 98%. Furthermore, the output of the AOTF is circular, collimated beam, which is ideally suited for coupling to a fiber, unlike the exit slit of a monochromator. High efficiency translates directly into higher sensitivity and therefore faster data acquisition.

Hands-Off Device

Once the AOTF or AOTF based spectrometer has been programmed to record a particular data set to compute a quality parameter or control a process, it requires no further attention. It can be programmed by an engineer or technician and then be operated in a hands-off mode or by an unskilled worker.

Use with Lock-in Amplifiers

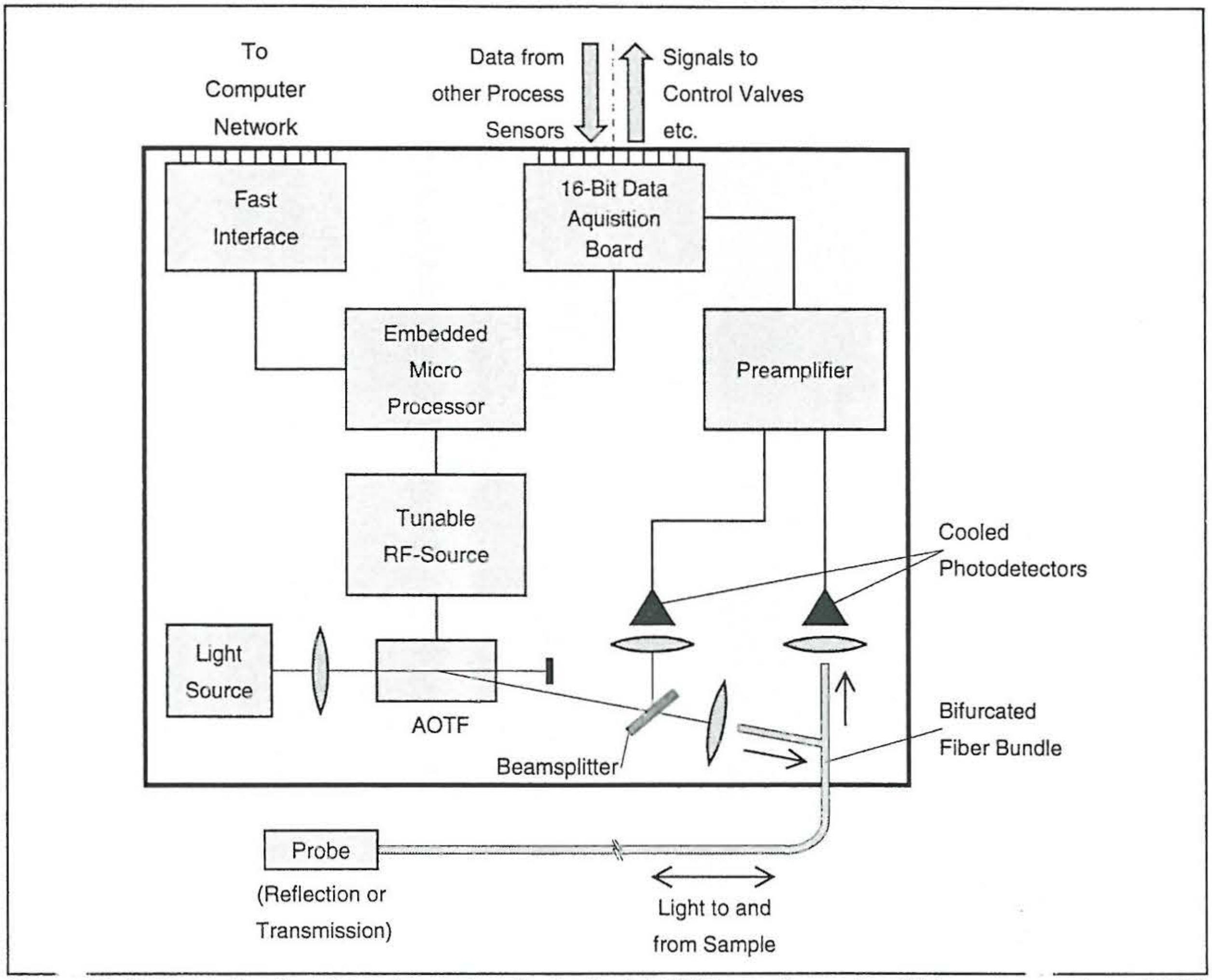
Both the wavelength and intensity of the selected light are controlled electronically and can be rapidly modulated. This makes the AOTF ideal for use with a lock-in (phase sensitive) amplifier.

PRACTICAL AOTF SPECTROMETERS

Applying AOTF technology to NIR spectroscopic applications is analogous to many other areas of applied technology; some applications require custom instrumentation whereas others can be served perfectly well by standard instruments. BRIMROSE has over eight years of experience with AOTF technology, and now offers standard and custom self-contained spectrometers (visible and NIR) based on their own AOTF devices, as well as stand-alone AOTF's which can be readily used to construct custom spectrometers. The basic elements of an AOTF spectrometer are shown in Figure 5, a schematic representation of the Brimrose Luminar 2000 AOTF. This particular spectrometer was designed primarily for closed loop industrial process control, including fiber coupling for remote operation. However, it is a versatile instrument that can also function as a powerful laboratory tool.

In this spectrometer, the output of a white light source (quartz halogen lamp) is collimated and directed into a TeO_2 AOTF. The monochromatic output beam from the AOTF is coupled into a bifurcated fiber bundle. The fiber exits the spectrometer and terminates in a probe designed for reflectivity or finite path absorption measurements. Light from the sample passes back along the fiber where it is focused on to a photodetector. The signal intensity at each wavelength is digitized by a high speed 16-bit A/D converter before being stored and/or analyzed by the CPU. Having an internal or dedicated CPU is extremely important for both industrial and laboratory applications, because analysis of NIR spectra always requires some degree of numerical computation. For process control applications, an embedded computer with appropriate software lends itself well to closed loop operation since the computer can be programmed not only to measure a process but to also control it by responding to the measured constituents. These responses can take the form

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com



Figu· 5. *Schematic showing elements of a typical AOTF spectrometer (Brimrose :·:minar 2000)*

of numerous kinds of digital or analog I/O to control flow valves, trip alarms or data transfer over a network to a central computer for storage or integration into a large scale process.

Figure 6 shows a transmission spectra of several alcoholic beverages recorded using this instrument. Notice the increased intensity of the methyl and methylene bands at approximately 1700 nm as the alcohol content increases.

CONCLUSIONS

NIR spectroscopy can be a powerful diagnostic in a wide variety of on-line or laboratory applications. However, to derive accurate compositional or quality parameters requires that data be recorded at multiple wavelengths in real time. A spectrometer must be able to repeatedly tune to these precise wavelengths reliably over long periods of time.

For industrial use it is also necessary that the spectrometer be rugged, flexible, and simple to operate. In addition, it is highly desirable that the instrument be compact and high speed in operation. Problems in meeting these requirements with "classical" spectroscopic technologies, for example grating spectrometers, have certainly delayed the wide spread deployment of NIR spectroscopy in industrial and commercial applications. With the advent of rugged, compact spectrometers based on AOTF technology, NIR spectroscopy is now set to fulfill its promise as an important on-line diagnostic tool. In fact, although systems using other technologies have been successfully deployed, AOTF technology is unique in its ability to satisfy all the criteria for hands-off NIR spectroscopy in the industrial environment.

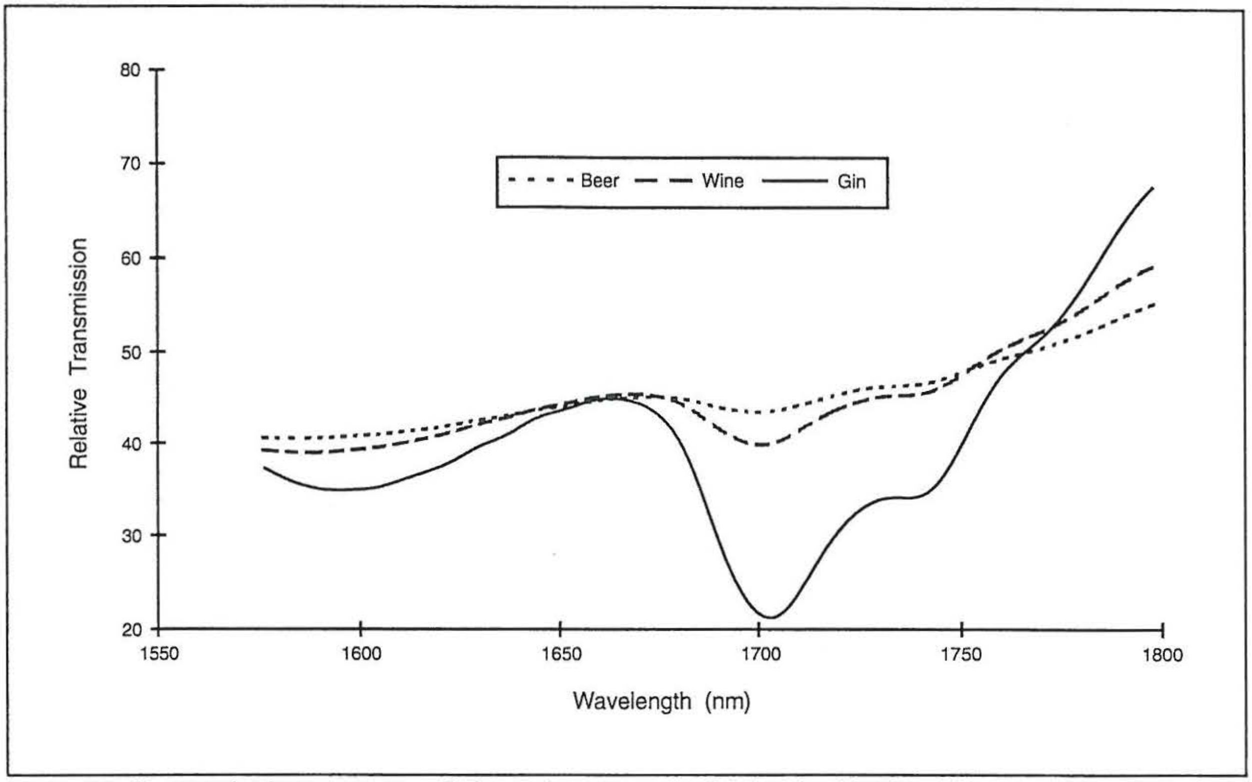


Figure 6. *Transmission spectra of three beverages obtained with the Brimrose Luminar 2000 Spectrometer which shows the increase in absorption at around 1700 nm as the alcohol content increases.*

ANY QUESTIONS ?

If you require further information on the topics discussed in this application note, or any other aspects of AOTF technology, contact our Applications Engineers. They will be happy to answer your questions and supply you with data and literature on specific BRIMROSE products.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Model Number Guide

Brimrose Corporation of America manufactures both standard (from the specification sheet) and custom (to customer specifications) Acousto-Optic Tunable Filters. The following Model Number Guide should be used to generate a model number for your special device.

M		S		W		W		P
	AF		-		-		-	

M = Material*

TE	- Tellurium Dioxide	(350 - 5000 nm)

S = Aperture Size

3	-	3mm x 3mm
5	-	5mm x 5mm
7	-	7mm x 7mm
10	-	10mm x 10mm
15	-	10mm x 15mm

W = Wavelength Range of Operation (in μm). Please note, that one AOTF will cover only a single RF Octave Bandwidth. Extended ranges can be provided per customer request at an additional cost.

P = Options

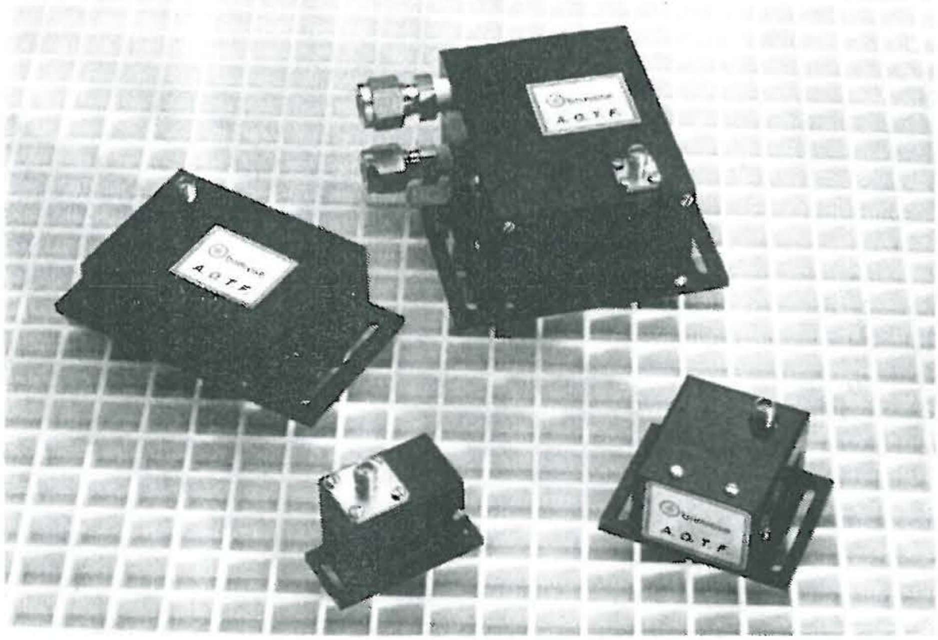
S	-	Standard Resolution
H	-	High Resolution
EH	-	Extra High Resolution
UH	-	Ultra High Resolution
I	-	Imaging Quality

AOTF Overview

Model Number	Spectral Resolution	Spectral Range (nm)	DE (%)	Material
TEAF_-.36-.52_	S or H	360-520	70	TeO_2
TEAF_-.40-.65_	S or H	400-650	70-90	TeO_2
TEAF_-.45-.70_	S or H	450-700	70-90	TeO_2
TEAF_-.50-1.0_	S or H	500-1000	70-90	TeO_2
TEAF_-.40-1.0-2CH	S	400-1000	50 - 60	TeO_2
TEAF_-.80-1.6_	S, H, or EH	800-1600	70-90	TeO_2
TEAF_-1.2-2.0_	S, H, or EH	1200-2000	25-35	TeO_2
TEAF_-1.5-3.0_	S, H, or EH	1500-3000	30	TeO_2
TEAF_-2.4-4.5_	S, H, or EH	2400-4500	40	TeO_2
TEAF_-0.8-1.6-UH	S, H, or EH	800-1600	50	TeO_2
TEAF_-1.2-1.7-UH	S, H, or, EH	1200-1700	50	TeO_2
TEAF_-1.5-2.4-UH	S, H, or, EH	1500-2400	40	TeO_2
TEAF_-2.4-3.2-UH	S, H, or, EH	2400-3200	35	TeO_2
TEAF_-3.2-4.5-UH	S, H, or, EH	3200-4500	30	TeO_2

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

UV - VIS AOTF



Item	Units	TEAF5-.36-.52
Substrate	-	TeO_2
Spectral Range	nm	360 - 520
Corresponding Drive Frequency	MHz	100 - 190
Optical Aperture *	mm	5.0 x 5.0
Acceptance Angle	deg	See Fig. 9
Spectral Resolution **	A	See Fig. 7 & 8
Drive Power	Watts	1
Peak Diffraction Efficiency ***	% @ nm	70
Package Type	-	#170

* Other optical apertures available upon request, ie: 3 x 3 mm, 5 x 5 mm
** Measured using collimated linearly polarized laser
*** The wavelength (frequency) relation may change (±10%) upon device alignment in the optical system

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

The Separation Angle, Acceptance Angle, and Spectral Resolution are a function of the wavelength and are shown in the following figures:

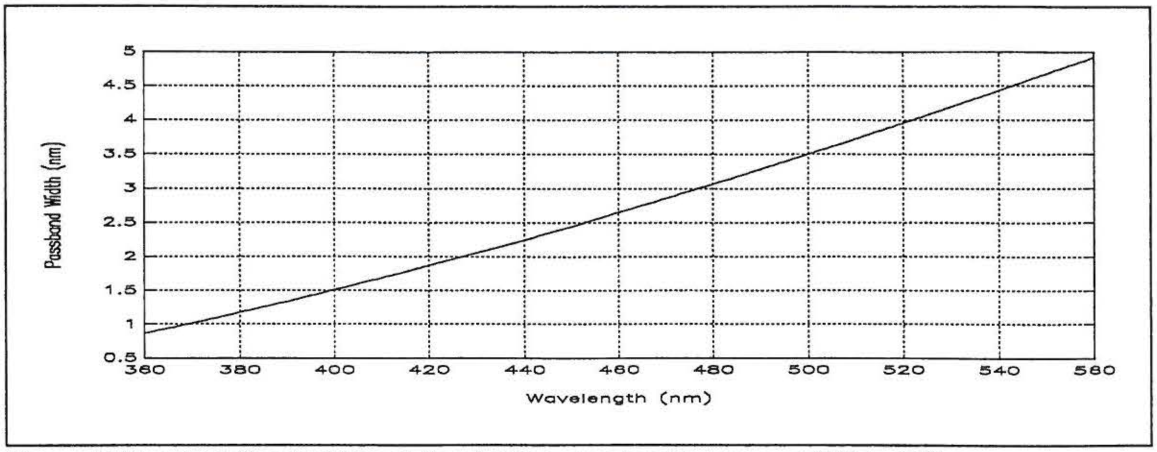


Figure 7 Standard Spectral Resolution for the wavelength range of 360 to 560 nm.

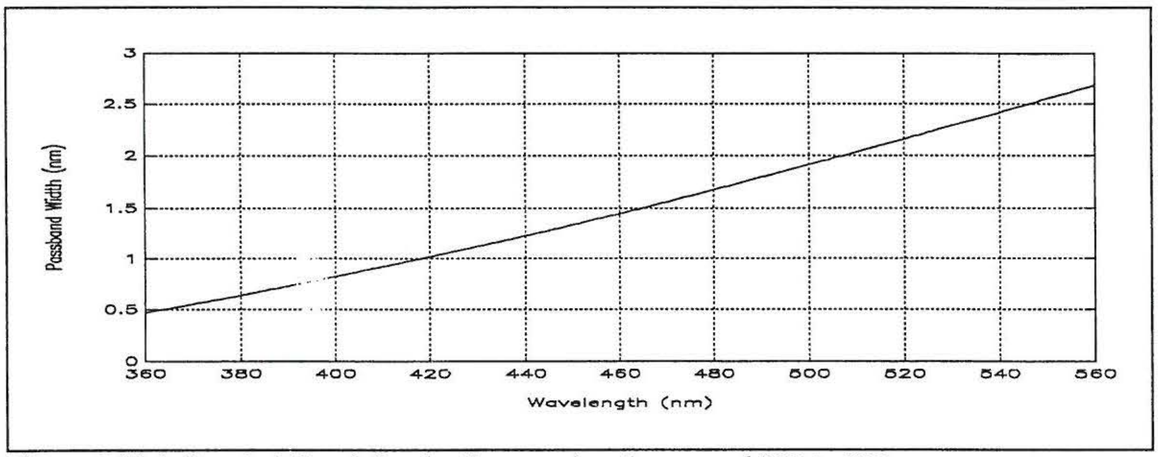


Figure 8 High Spectral Resolution for the wavelength range of 360 to 560 nm.

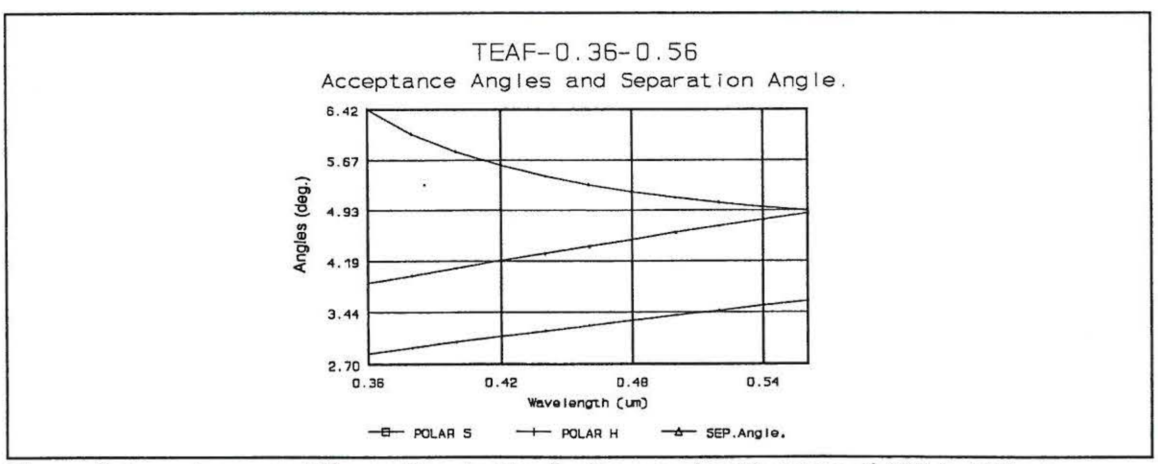
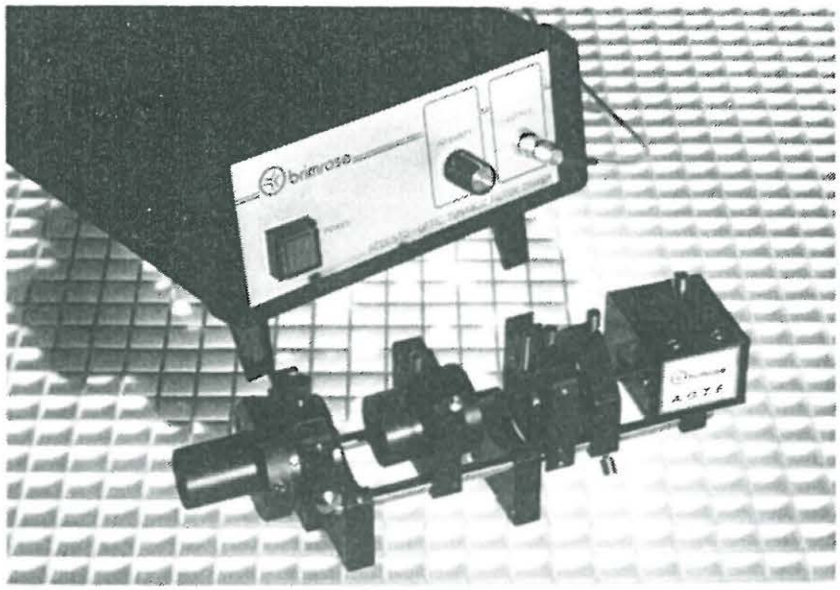


Figure 9 Acceptance and Separation Angles for the wavelength range of 360 to 560 nm.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Visible AOTF



Acousto-Optic Tunable Filter TeO_2

Model No.	Spectral Range (nm)	Corresponding Drive Frequency (MHz)	Spectral Resolution
TEAF__-.40-.65	400 - 650	220 - 110	S or H
TEAF__-.45-.70	450 - 700	180 - 100	S or H
TEAF__-.50-1.0	500 - 1000	155 - 70	S or H
TEAF__-.40-1.0-2CH	400 - 1000	220 - 70	S

Each of the above AOTF's is available with the following apertures:

	Standard Optical Apertures in mm			
Optical Aperture	3.0 x 3.0	5.0 x 5.0	7.0 x 7.0	10.0 X 10.0
Model No.	TEAF3-XX-YY	TEAF5-XX-YY	TEAF7-XX-YY	TEAF10-XX-YY
Peak Diffraction Efficiency	90 %	85 %	75 %	70 %
Drive Power (Watts)	0.5 - 1.0	0.5 - 1.0	1.0 - 1.5	1.0 - 1.5
Package Type	#170 (TE Cooled available upon request)		#170 (TE Cooled available upon request)	
RF Connector	Standard SMA			

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

The Separation Angle, Acceptance Angle, and Spectral Resolution are a function of the wavelength and are shown in the following figures:

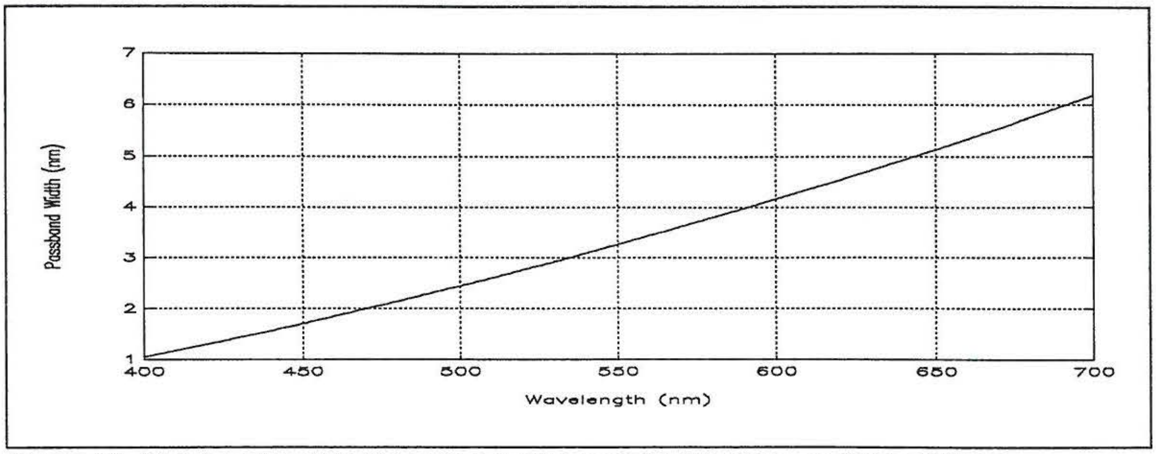


Figure 10. Standard Spectral Resolution for the wavelength range of 400 to 700 nm.

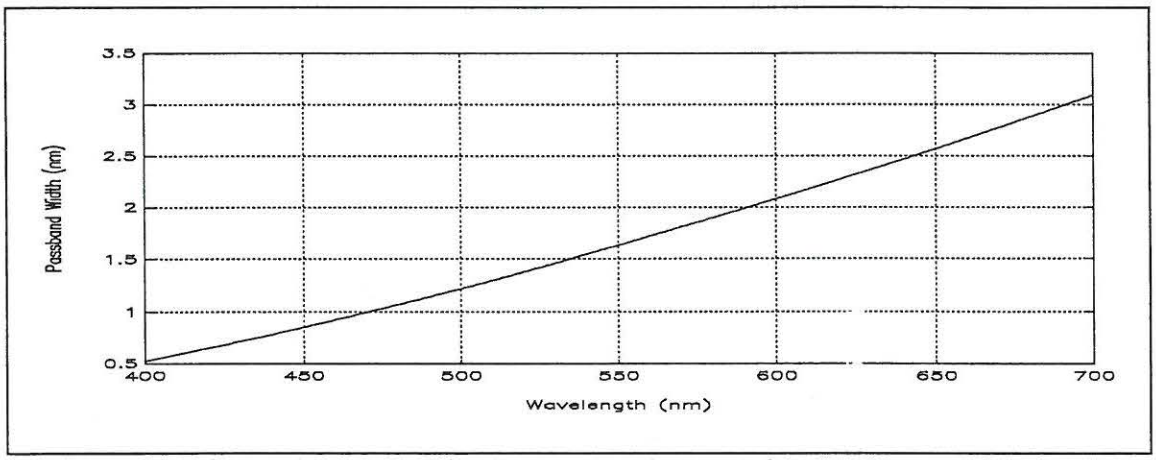


Figure 11. High Spectral Resolution for the wavelength range of 400 to 700 nm.

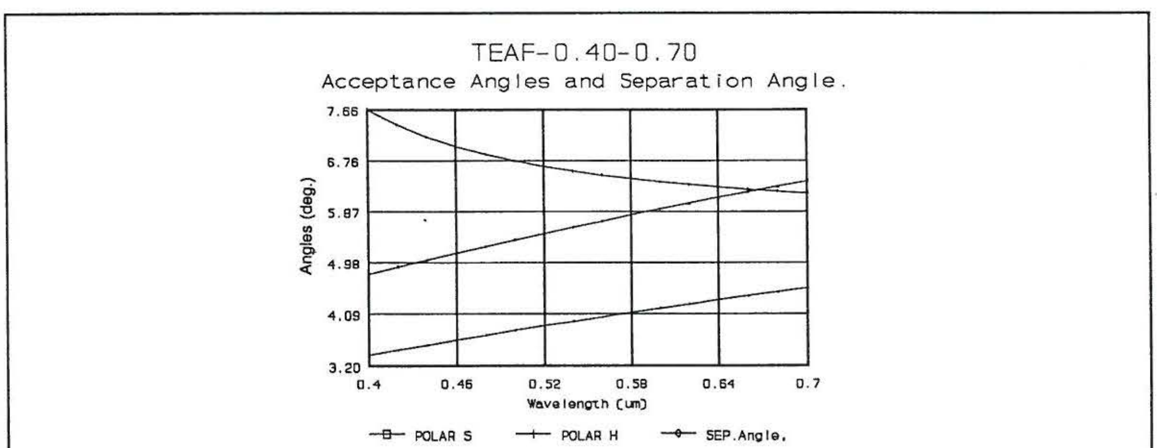


Figure 12. Acceptance and Separation Angles for the wavelength range of 400 to 700 nm.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

The Separation Angle, Acceptance Angle, and Spectral Resolution are a function of the wavelength and are shown in the following figures:

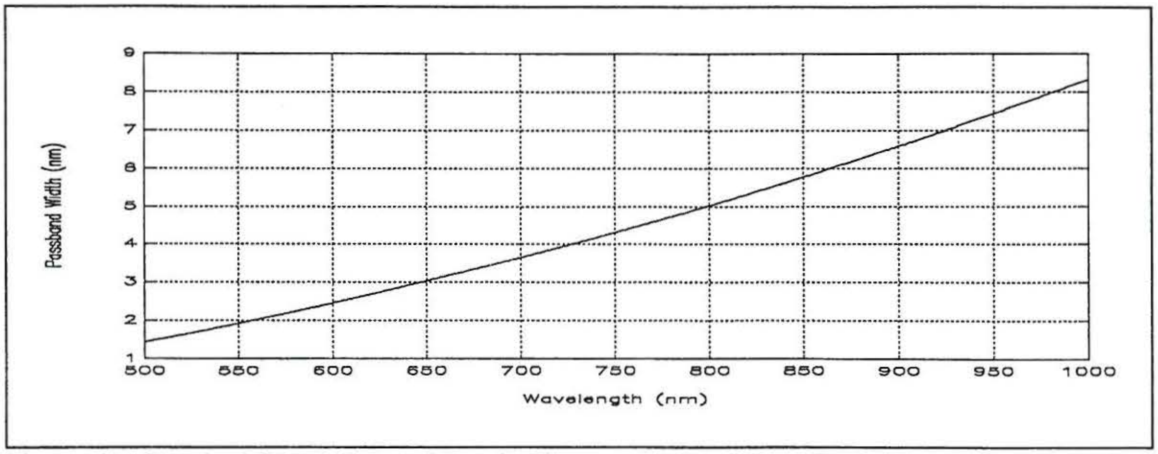


Figure 13. Standard Spectral Resolution for the wavelength range of 500 to 1000 nm.

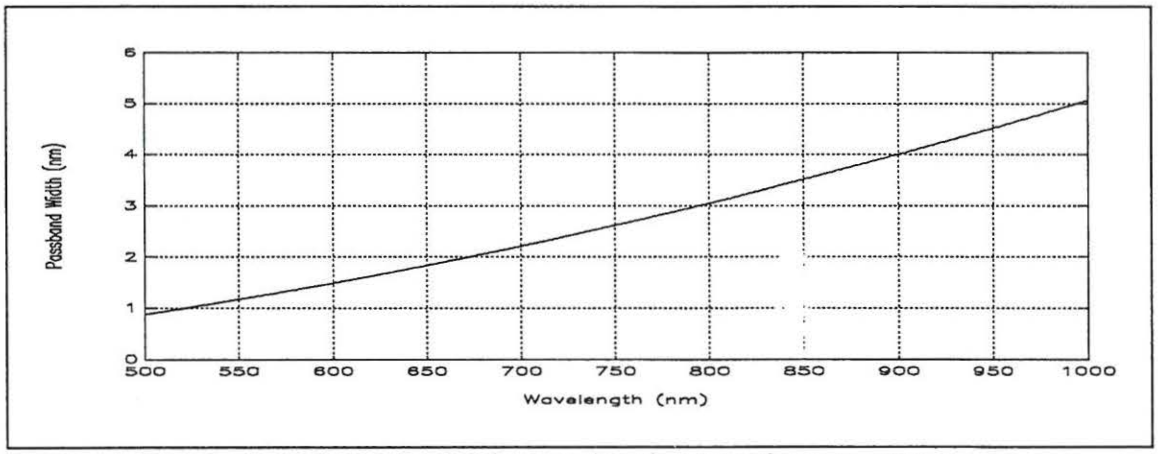


Figure 14. High Spectral Resolution for the wavelength range of 500 to 1000 nm.

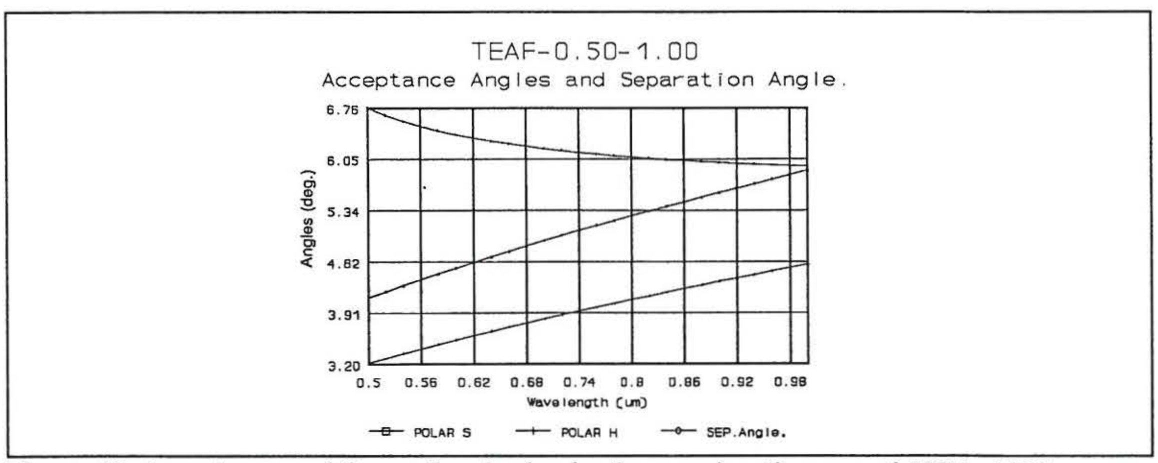


Figure 15. Acceptance and Separation Angles for the wavelength range of 500 to 1000 nm.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

IR AOTF

Acousto-Optic Tunable Filter TeO_2

Model No.	Spectral Range (nm)	Corresponding Drive Frequency (MHz)	Spectral Resolution	Diffraction Efficiency
TEAF__-.80-1.6	800 - 1600	130 - 60	S, H or EH	50 %
TEAF__-1.2-2.0	1200 - 2000	90 - 50	S, H or EH	50 %
TEAF__-1.5-3.0	1500 - 3000	68 - 34	S, H or EH	40 %
TEAF__-2.4-4.5	2400 - 4500	40 - 20	S, H or EH	35 %

Each of the above AOTF's is available with the following apertures:

	Standard Optical Apertures in mm			
Optical Aperture	3.0 x 3.0	5.0 x 5.0	7.0 x 7.0	10.0 X 10.0
Model No.	TEAF3-XX-YY	TEAF5-XX-YY	TEAF7-XX-YY	TEAF10-XX-YY
Drive Power (Watts)	2.0 - 4.0	2.0 - 4.0	2.0 - 4.0	2.0 - 4.0
Package Type	#170 (TE Cooled available upon request)		#170 (TE Cooled available upon request)	
Connectors	SMA			

Other optical apertures available upon request.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

The Separation Angle, Acceptance Angle, and Spectral Resolution are a function of the wavelength and are shown in the following figures:

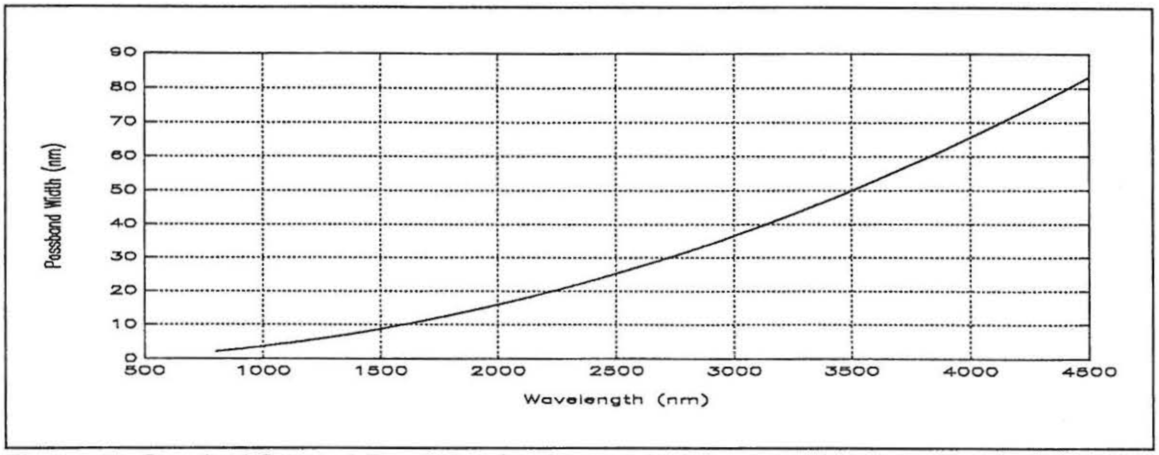


Figure 16. Standard Spectral Resolution for the wavelength range of 1000 to 4500 nm.

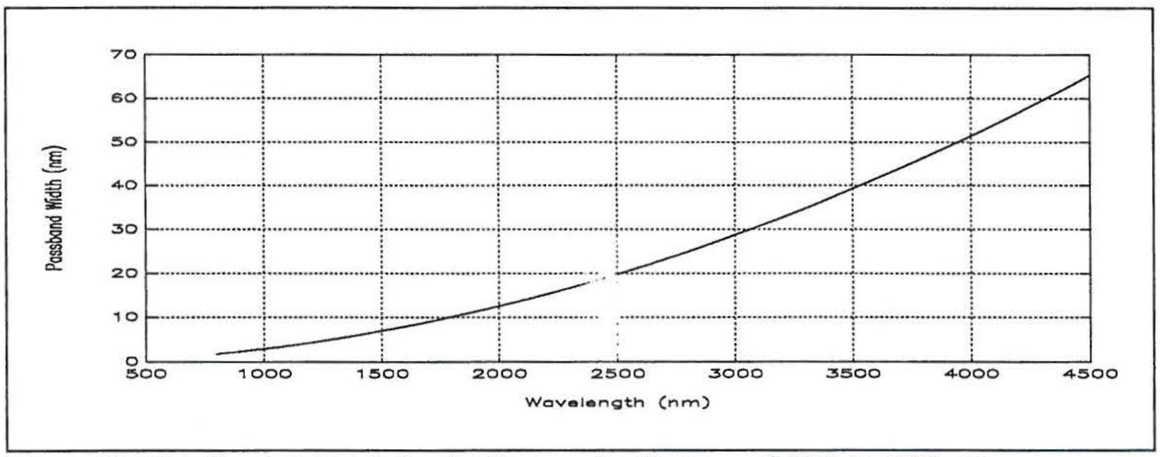


Figure 17. High Spectral Resolution for the wavelength range of 1000 to 4500 nm.

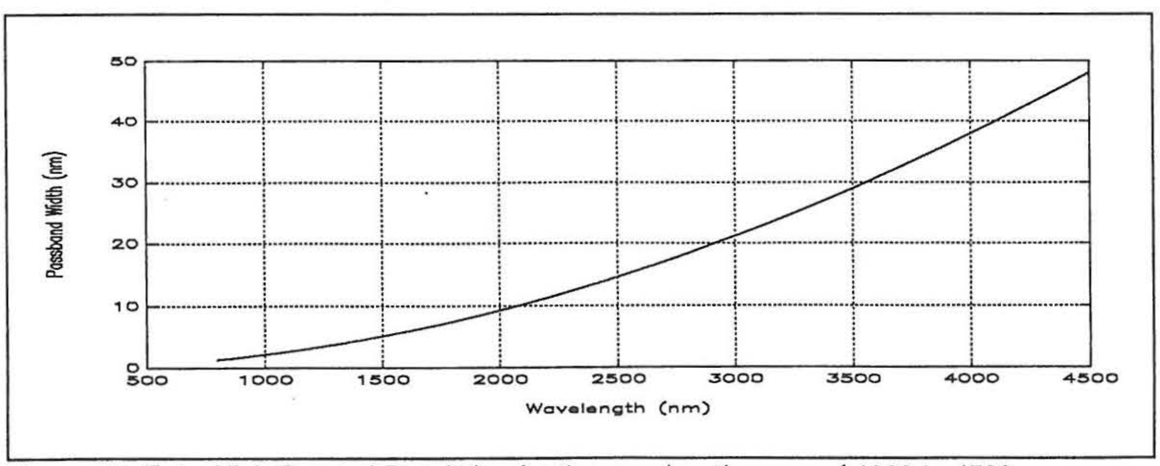


Figure 18. Extra High Spectral Resolution for the wavelength range of 1000 to 4500 nm.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

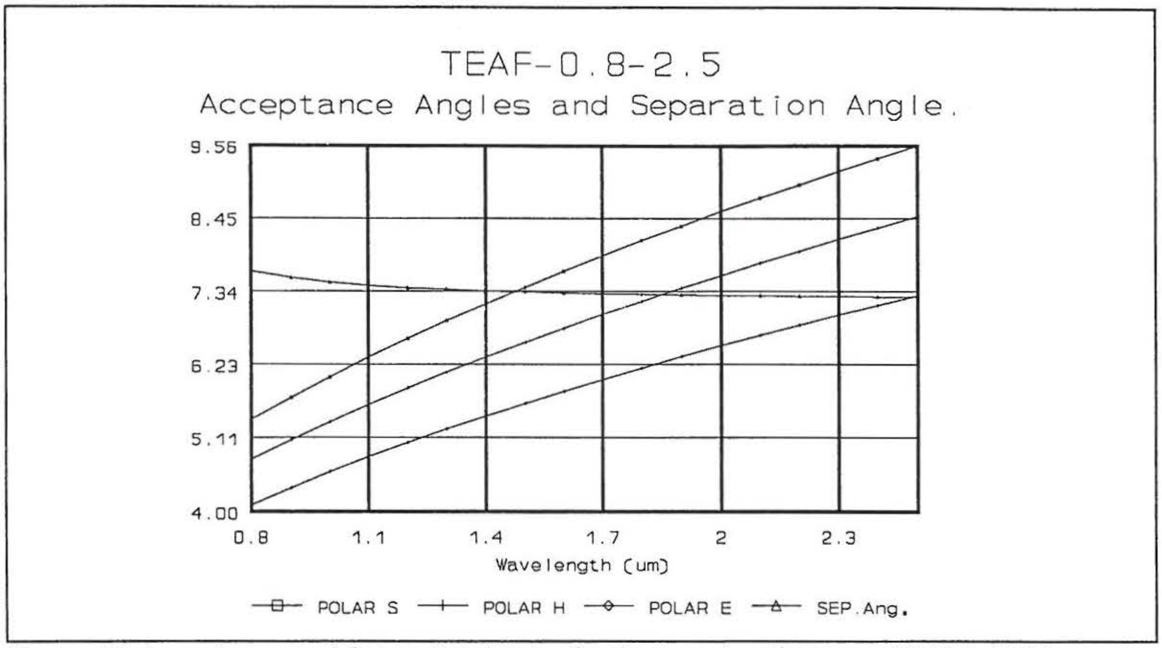


Figure 19. Acceptance and Separation Angles for the wavelength range of 800 to 2500 nm.

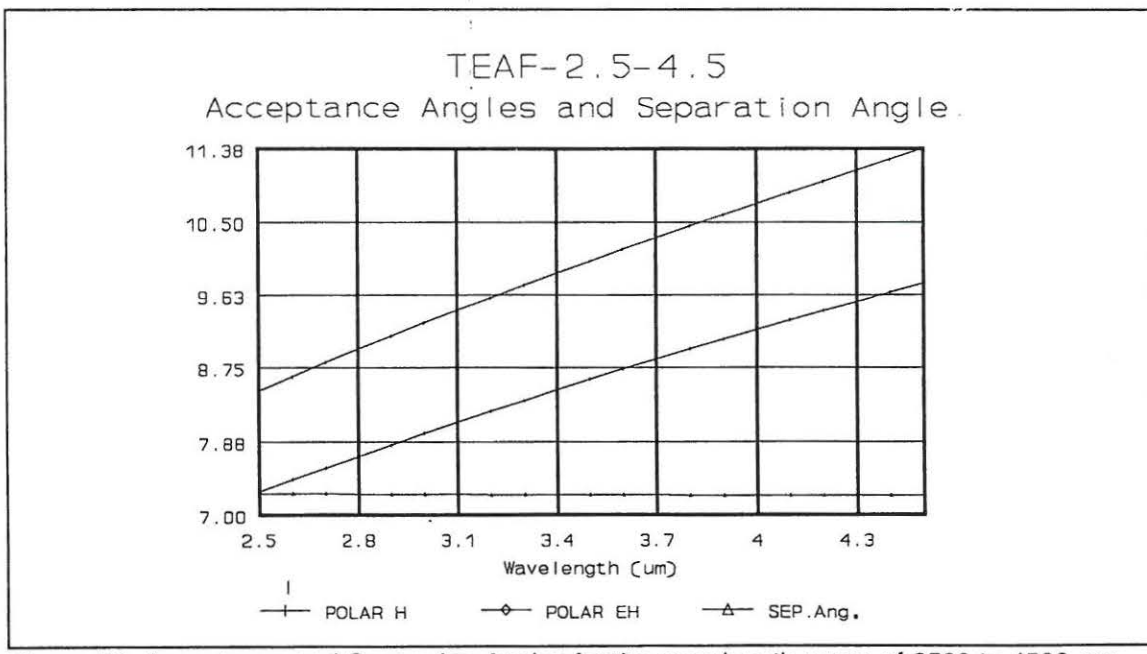


Figure 20. Acceptance and Separation Angles for the wavelength range of 2500 to 4500 nm.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Ultra-High Resolution IR AOTF

Acousto-Optic Tunable Filter TeO_2

Model No.	Spectral Range (nm)	Corresponding Frequency (MHz)	Spectral Resolution	Diffraction Efficiency
TEAF__-.80-1.6-UH-__	800 - 1600	190 - 90	S, H or EH	50 %
TEAF__-1.2-1.7-UH-__	1200 - 1700	120 - 80	S, H or EH	50 %
TEAF__-1.5-2.4-UH-__	1500 - 2400	90 - 55	S, H or EH	40 %
TEAF__-2.4-3.2-UH-__	2400 - 3200	55 - 40	S, H or EH	35 %
TEAF__-3.2-4.5-UH__	3200 - 4500	45 - 30	S, H or EH	30 %

Each of the above AOTF's is available with the following apertures:

	Standard Optical Apertures in mm			
Optical Aperture	3.0 x 3.0	5.0 x 5.	7.0 x 7.0	10.0 X 10.0
Model No.	TEAF3-XX-YY	TEAF5-XX-YY	TEAF7-XX-YY	TEAF10-XX-YY
Drive Power (Watts)	3.0 - 4.0	3.0 - 4.0	3.0 - 5.0	3.0 - 5.0
Package Type	#190	#190	#190	#190
Connectors	SMA			

Other optical apertures are available upon request.

brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

The Separation Angle, Acceptance Angle, and Spectral Resolution are a function of the wavelength and are shown in the following figures:

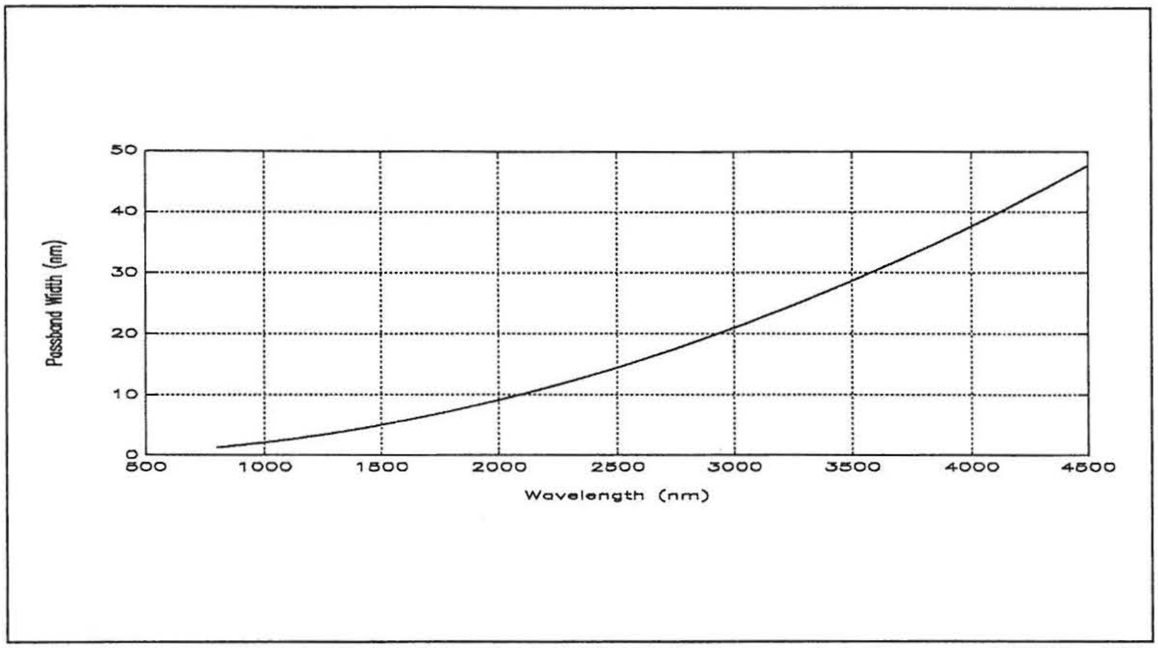


Figure 21. Standard Spectral Resolution for UH AOTF's for the wavelength range of 1000 to 4500 nm.

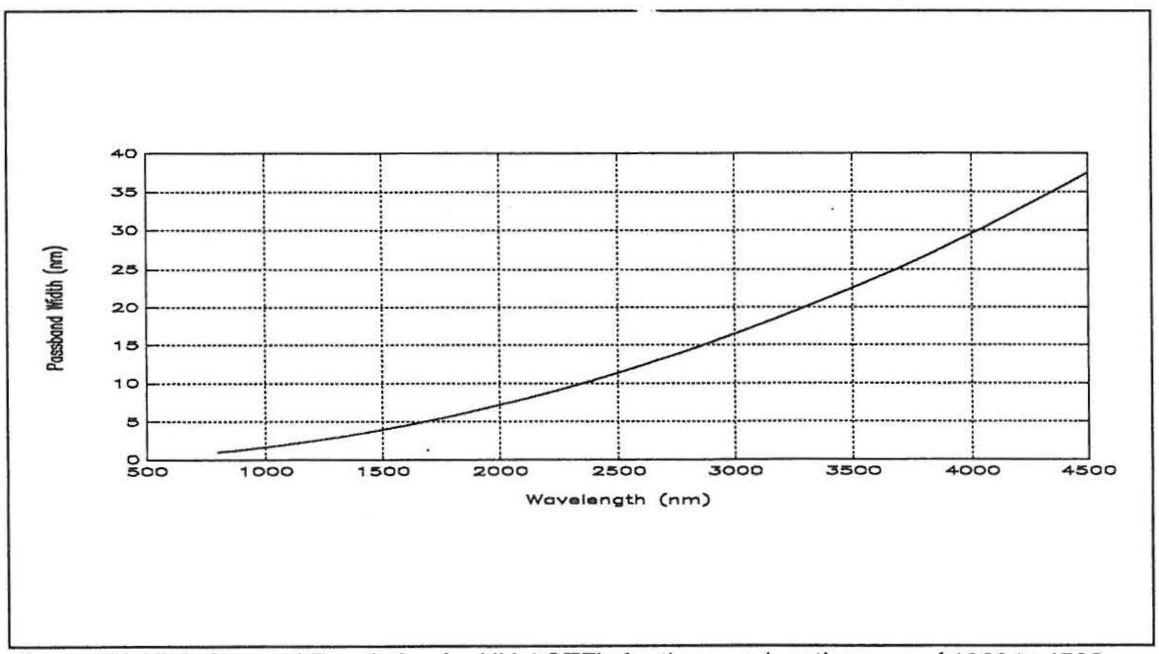


Figure 22. High Spectral Resolution for UH AOTF's for the wavelength range of 1000 to 4500 nm.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

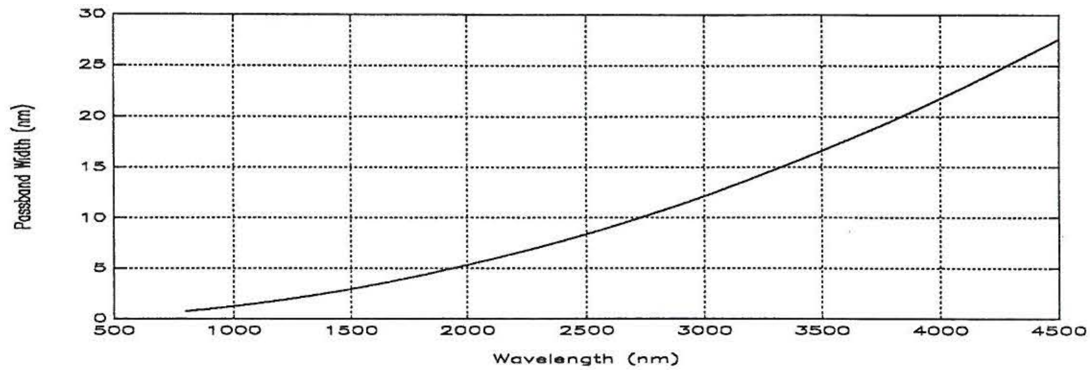


Figure 23. Extra High Spectral Resolution for UH AOTF's for the wavelength range of 1000 to 4500 nm.

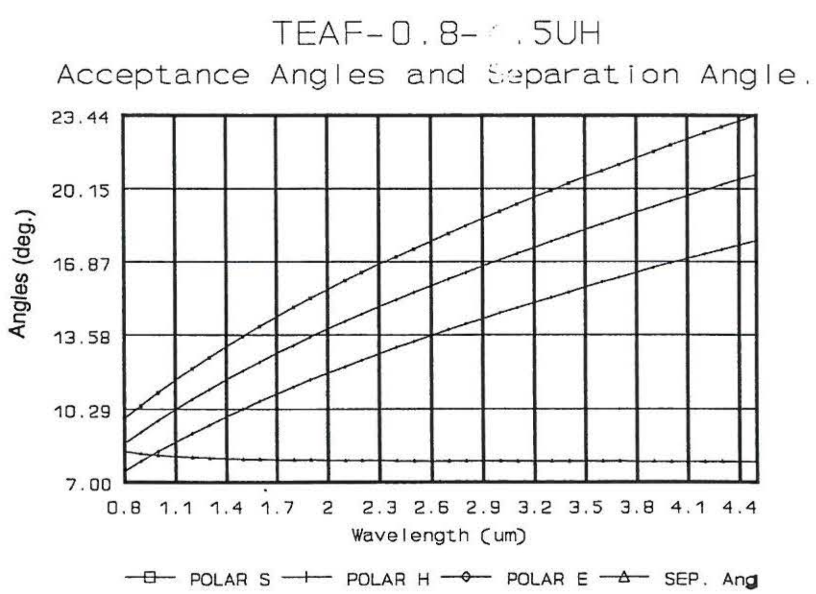


Figure 24. Acceptance and Separation Angles for UH AOTF's for the wavelength range of 1000 to 4500 nm.

Ultra High Resolution AOTF for Raman Spectroscopy

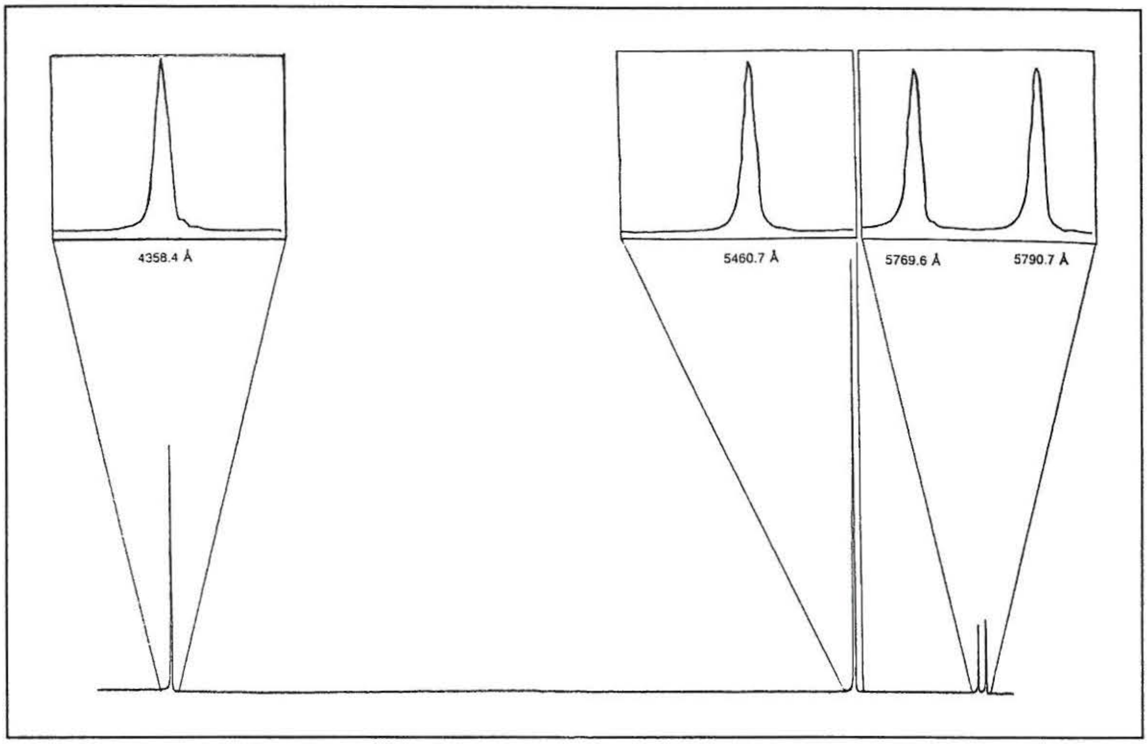


Figure 25. A visible spectrum of the miniature mercury lamp recorded by the prototype spectrophotometer based on the new AOTF. The RF frequency is scanned uniformly from 353 MHz down to 230 MHz.

PARAMETER	UNIT	TEAF5-.40-.65 UH
Wavelength Range	nm	400 - 650
Corresponding RF Frequency	MHz	200 - 400
Spectral Resolution	Å	1.5 @ 400 nm 3.2 @ 633 nm
RF Drive Power	Watt	2.0
Time Delay	μsec	10
Rise Time	μsec	30
Input/Output Polarization	-	Vertical/Horizontal
RF Connector	-	SMA
Acceptance Angle	deg	±1.5°
Diffraction Efficiency	%	> 50
Aperture	mm	5 x 7

brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

-DDS

Direct Digital RF Synthesizer for IBM Compatible PCs

Model	-DDS
Frequency*	100 MHz to 200 MHz
Frequency Step Size**	30 Hz
Frequency Accuracy	0.01% absolute (100 ppm); 15°C to 75°C
Frequency Switching Speed	250 μs maximum (from f_{min} to f_{max})
Phase Noise	< -45 dBc/Hz @ 1 KHz in 1 Hz bandwidth
Power Output	+33 dBm typical (2 Watts)***
Power Control	12 bit attenuator with 25 dB range (minimum)
Output Impedance	50 ohms
Output Connector	SMA jack on front panel

* *The AOTF Controller will only operate over a range required to interface to the purchased AOTF device. The controller card will be set at the factory for the target device parameters.*

** *This is a parameter of the RF driver; however, the AOTF device will not have this resolution.*

*** *2.0 Watts Standard.*

The DDS Model AOTF Controller is an amplitude controlled Direct Digital RF synthesizer board for IBM compatible PC systems. The DDS board interfaces with an external RF amplifier unit that connects to the AOTF device. The interface unit operates from a standard 110 VAC, 60 Hz or 220 VAC, 50 Hz line and draws 1.5 A.

Applications for this driver include:

- AOTF Wavelength Controller for TeO_2 AOTFs.
- Programmable access to laser lines from a multi-line laser source.
- Control AOTF 1st and 2nd order beam wavelength and amplitude.
- Level intensity output of incoherent or coherent laser light source.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

-DDS

Computer Requirements:

The computers used must be IBM compatible and equipped with 16-bit ISA (Industry Standard Architecture) expansion slots.

Software Provided:

The synthesizer software provides frequency and amplitude control of the output RF signal. A Windows 3.11/95 version is available which provides an easy to use graphical interface for controlling the DDS.

Options:

R.F. Modulation Options

A.M.:	Analog Amplitude Modulation
A.S.K.:	Amplitude Shift Keying or Digital Amplitude Modulation
F.M.:	Analog Frequency Modulation
F.S.K.:	Frequency Shift Keying or Digital Frequency Modulation
P.A.M.:	Pulse Amplitude Modulation (internal or external pulse generator available)

Other Options

DCn:	Customer Supplied DC "n" volts
B:	BNC connectors in place of SMAs for RF output
E:	200-250 VAC 50-400 Hz power
M:	O.E.M. or customer specified enclosure or outline
X,Y,Z:	Customer specific option

AOTF Controller System

-PPS

PC controlled AOTF drivers

Model	-PPS
Frequency Range*	100.0 to 200.0 MHz
Frequency Step Size	15,625 Hz
Frequency Accuracy	0.010% absolute (100 ppm); 0°C to 60°C
Frequency Switching Speed	15 ms typ (from f_{min} to f_{max})
Phase Noise	< -45 dBc/Hz @ 1 KHz in 1 Hz bandwidth
Power Output	+33.0 dBm typ.(2.0 W)**
Power Control	20dB variable amplitude
Output Impedance	50 ohms
Output Connector	SMA jack on front panel

* *Ti. frequency range will be adjusted based on the AOTF requirements.*

** *2.υ Watts standard, output 30 Watt optional. Maximum power level preset at factory for optimu.. AOTF performance.*

The PPS Model AOTF Controller is a high performance RF frequency synthesizer incorporated into a self-contained case with AC power supply. A modular cable with a DB25 connector interface allows frequency control via the Personal Computer parallel (printer) port.

Applications for this driver include:

- AOTF Wavelength Controller for TeO_2 AOTF devices.
- Level intensity output of incoherent or coherent light source at any wavelength with built-in feedback loop.

Front Panel Controls:

1. Power switch.
2. Power output connector (SMA).

Computer Requirements:

Any IBM compatible computer (PC, XT, AT) with a printer port (parallel) can be used. Any language able to communicate with the printer port may be used.

Software Provided:

The synthesizer software provides frequency and amplitude control of the output RF signal when the synthesizer is connected to a PC's parallel port. A DOS version is available which provides an easy to use graphical interface for controlling the PPS.

Options:

R.F. Modulation Options

A.M.:	Analog Amplitude Modulation
A.N.:	RF Attenuator, 0-20 dB, front panel knob controlled
A.S.K.:	Amplitude Shift Keying or Digital Amplitude Modulation
F.M.:	Analog Frequency Modulation
F.S.K.:	Frequency Shift Keying or Digital Frequency Modulation
P.A.M.:	Pulse Amplitude Modulation (internal or external pulse generator available)

Other Options

DCn:	Customer Supplied DC "n" volts
B:	BNC connectors in place of SMAs for RF output
E:	200-250 VAC 50-400 Hz power
M:	O.E.M. or customer specified enclosure or outline
X,Y,Z:	Customer specific option

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

AOTF Controller System

-SPS

PC controlled AOTF drivers

Model	-SPS
Frequency Range*	100.0 to 200.0 MHz
Frequency Step Size	15,625 Hz
Frequency Accuracy	0.010% absolute (100 ppm); 0°C to 60°C
Frequency Switching Speed	15 ms typ (from f_{min} to f_{max})
Phase Noise	< -45 dBc/Hz @ 1 KHz in 1 Hz bandwidth
Power Output	+33.0 dBm typ.(2.0 W)**
Power Control	20dB variable amplitude
Output Impedance	50 ohms
Output Connector	SMA jack on front panel

* *The frequency range will be adjusted based on AOTF requirements.*
** *2.0 Watt standard, output 30 Watt optional. Maximum power level preset at factory for optimum AOTF performance.*

The SPS Model AOTF Controller is a high performance RF frequency synthesizer incorporated into a self-contained case with AC power supply. A modular cable with a DB9 connector interface allows frequency control via the Personal Computer serial port.

Applications for this driver include:

- AOTF Wavelength Controller for TeO_2 AOTF devices
- Level intensity output of incoherent or coherent light source at any wavelength with built-in feedback loop.

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Front Panel Controls:

1. Power switch.
2. Power output connector (SMA).

Computer Requirements:

Any IBM compatible computer (PC, XT, AT) with a serial port can be used. Any language able to communicate with the serial port may be used.

Software Provided:

The synthesizer software provides frequency and amplitude control of the output RF signal when the synthesizer is connected to a PC's serial port. A Windows 3.11/95 version is available which provides an easy to use graphical interface for controlling the SPS.

Options:

R.F. Modulation Options

A.M.:	Analog Amplitude Modulation
A.S.K.:	Amplitude Shift Keying or Digital Amplitude Modulation
F.M.:	Analog Frequency Modulation
F.S.K.:	Frequency Shift Keying or Digital Frequency Modulation
P.A.M.:	Pulse Amplitude Modulation (internal or external pulse generator available)

Other Options

DCn:	Customer Supplied DC "n" volts
B:	BNC connectors in place of SMAs for RF output
E:	200-250 VAC 50-400 Hz power
M:	O.E.M. or customer specified enclosure or outline
X,Y,Z:	Customer specific option

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

-VCO

Front Panel Controls:

1. Amplitude control knob (optional).
2. Power switch.
3. Power output connector (SMA).

Options:

R.F. Modulation Options

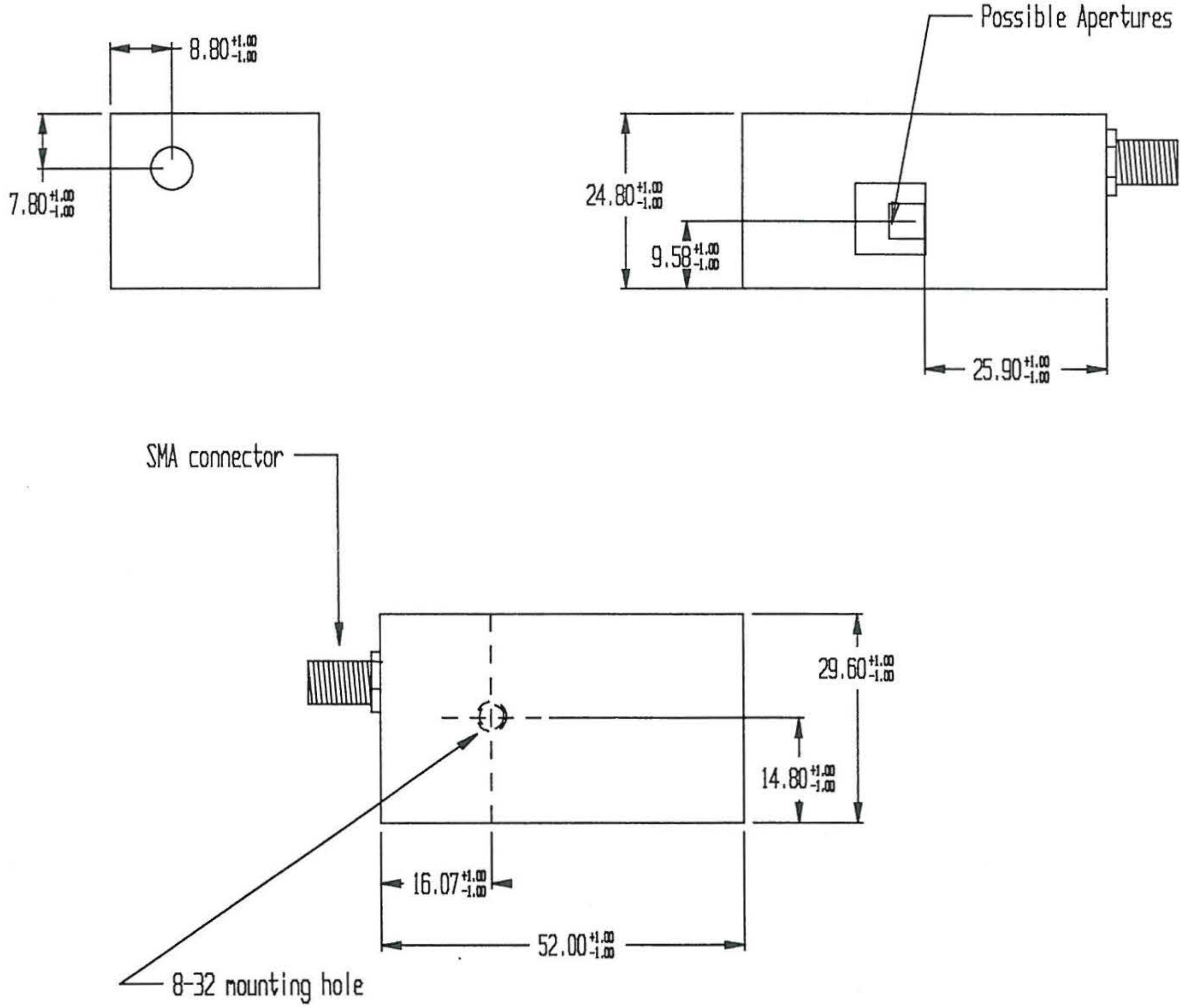
A.M.:	Analog Amplitude Modulation
A.S.K.:	Amplitude Shift Keying or Digital Amplitude Modulation
F.M.:	Analog Frequency Modulation
F.S.K.:	Frequency Shift Keying or Digital Frequency Modulation
P.A.M.:	Pulse Amplitude Modulation (internal or external pulse generator available)

Other Options

DCn:	Customer Supplied DC "n" volts
B:	BNC connectors in place of SMAs for RF output
E:	200-250 VAC 50-400 Hz power
M:	O.E.M. or customer specified enclosure or outline
X,Y,Z:	Customer specific option

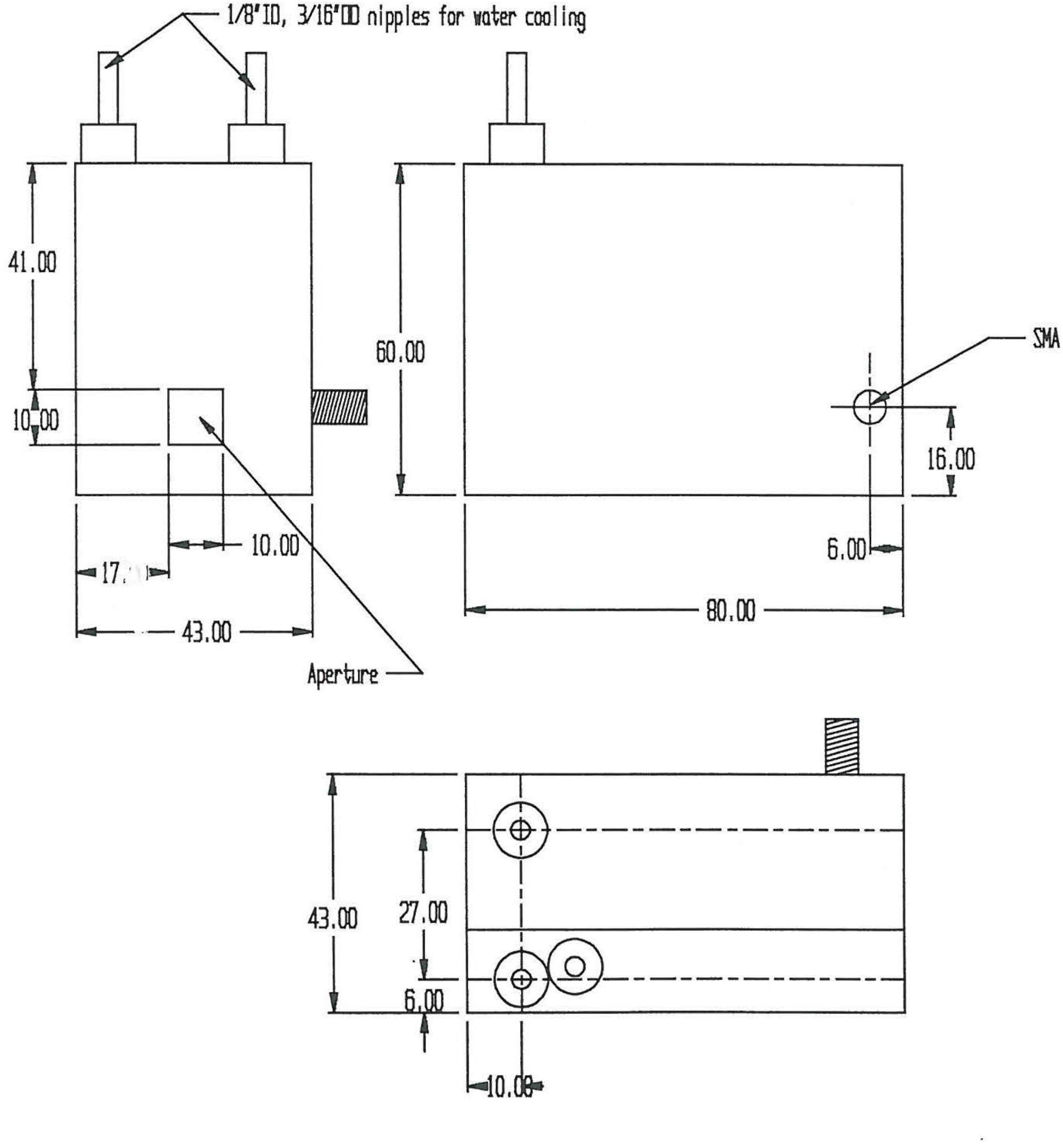
BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Package Drawing 170



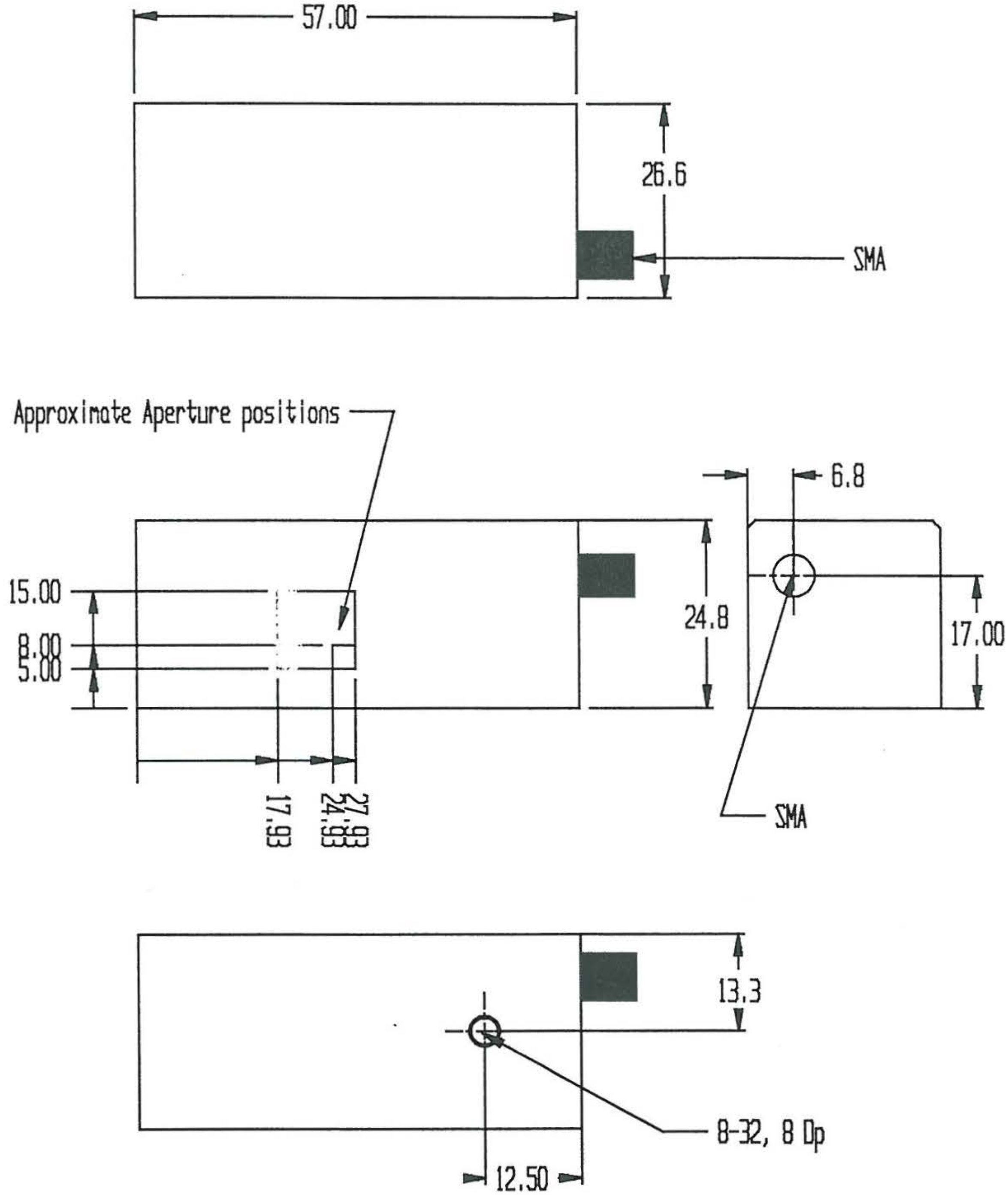
BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Package Drawing 360



BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Package Drawing 190



BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

Other Products

- MHz/GHz Acousto-Optic Modulators, Deflectors, and Frequency Shifters
- Acousto-Optic UV/VIS/IR MHz/GHz Mode Lockers, Cavity Dumpers, and Q-Switches
- Fiber Optically Pigtailed A-O Devices
- RF Synthesizers, Power Supplies, and Power Amplifiers for the Acousto-Optic Devices
- Visible, NIR, and IR Acousto-Optic Tunable Filters Imaging sub-systems and systems
- VIS/IR Imaging and Spectroscopy Systems
- NIR AOTF Spectrometer for on-line process control and laboratory application
- Diode Pumped Solid-State Lasers
- Liquid Nitrogen, Joule Thompson, and Split-Sterling Photovoltaic IR Detectors

BRIMROSE
brimrose corporation of america • 5024 campbell blvd., baltimore, maryland 21236 usa
410/931-7200 • fax: 410/931-7206 • e-mail: office@brimrose.com • http://www.brimrose.com

International Representatives

Laser Electronics
P.O. Box 221 • Nerang, Queensland 4211 **Australia**
TEL: 61 755 96 0177 • FAX: 61 755 96 3530 • E-mail: las.el@s130.aone.net.au

Melles Griot, Western Office
1055 Thistlewood Drive • Victoria, B.C. V8X 4Z7 **Canada**
TEL: (604)658-1923 • FAX: (604)658-8203 • E-mail: sales@canada.mellesgriot.com

Melles Griot, Eastern Office
Unit 104, 18 Antares Drive • Nepean, Ontario K2E 1A9 **Canada**
TEL: (613)226-5880 • TOLL FREE: 1-800-267-3497 • FAX: (613)226-5885
• E-mail: mgcda@globalx.net

Rocotech
The New House, Windsor Road • Gerrards Cross, Bucks SL9 7NF **England**
TEL: 441 753 890 809 • FAX: 441 753 890 655 • E-mail: sales@rocotech.co.uk

Laser 2000 S.A.
Parc d'affaires • 3 rue de la Plaine • 78860 Saint-Nom la Bretèche **France**
TEL: 33 1 30 80 00 60 • FAX: 33 1 30 80 00 40 • E-mail: info@laser2000.fr

Laser 2000 GmbH
Argelsrieder Feld 14 • D-82234 Weßling **Germany**
TEL: 49 8153 405 0 • FAX: 49 8153 405 33 • E-mail: info@laser2000.de

ATS, Ltd.
33 Ben Gurion Street, POB 5085 • Herzliya 46101 **Israel**
TEL: 972 9 9574111 • FAX: 972 9 9574447, 972 9 9561221

Laser Optronic
Via Quaranta, 55 • 20139 Milano **Italy**
TEL: 39 2 57 46 51 • FAX: 39 2 57 4101 27 • E-mail: 101522.2747@CompuServe.com

Opto Science, Inc.
Naitocho Bldg. 7F • Naitocho • 1-Banchi Shinjuku-ku • Tokyo 160 **Japan**
TEL: 81 3 3356 1064 • FAX: 81 3 3356 3466 • E-mail: optoscnc@mail.at-m.or.jp

MJL Crystek, Inc.
PO Box 21 • 399-8 Doryong-Dong • Yusung-Gu • Taejon 305-600 **Korea**
TEL: 82 42 861 8070 • FAX: 82 42 861 8073 • E-mail: mjl@soback.kornet.nm.kr

Eurotek International, Ltd.
Al. Lotników 32/46 • 02-668 Warszawa **Poland**
TEL: 48 22 8 43 79 40 • FAX: 48 22 8 43 61 43 • E-mail: inbox@eurotek.com.pl

Unice E-O Services Inc.
No. 25, Chung Ming Road • Chung Li **Taiwan**
TEL: 886 3 491 2245 •FAX: 886 3 491 2243 • E-mail:unice1@ms4.hinet.net